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The Effect of Subsurface Layered Trifluralin and Dicamba on Field Bindweed, Winter Wheat, and Corn

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THE EFFECT OF SUBSURFACE LAYERED TRIFLURALIN AND DICAMBA ON FIELD BINDWEED, WINTER WHEAT, AND CORN

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LAYERED TRIFLURALIN AND DICAMBA ON FIELD
BINDWEED, WINTER WHEAT, AND CORN

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Field bindweed (Convolvulus arvensis L.) is a deep-rooted, perennial weed that competes with crop plants for water, light, and nutrients resulting in severe crop losses, especially in low rainfall areas. It has long been recognized as a serious weed problem in many areas of the central and far western states. The ability of field bindweed to store large amounts of food reserves in its underground parts has allowed it to escape nearly all methods of attempted elimination. Presently, the most successful methods of field bindweed elimination are either a 2- to 3-year intensive fallow program or a 3- to 4-year program of a combination of cropping, chemicals and cultivation. These systems are expensive and laborious for the farmer. Therefore, a more effective method of field bindweed elimination would benefit the South Dakota farmer.

The application of a layer of a,a,a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine (trifluralin) beneath the soil surface has shown potential as a method of controlling field bindweed. The purposes of this study were (1) to further evaluate the control of field bindweed treated with a subsurface layer of trifluralin, (2) to determine if field bindweed control can be increased by tank-mixing trifluralin and 3,6-dichloro-o-anisic acid (dicamba), and (3) to determine if these treatments could be used in a productive cropping system.

LITERATURE REVIEW

Field bindweed is ranked as the number one primary noxious weed problem in South Dakota. Its resistance to control, widespread infestation, and a 30 to 100% yield reduction of agronomic crops grown on infested acres are the basis for the number one ranking (45).

Field bindweed (5, 20, 41) is a perennial plant with deep roots and low-growing, twining stems. Its leaves are variable in size, generally arrow-shaped, with acute basal lobes. The flowers are bell-shaped, about 2 cm in diameter, and are predominantly white; however, various shades of pink do occur. Seeds are developed in two-celled capsules, usually two seeds per cell. Mature seeds may remain viable in the soil for more than twenty years (51).

Field bindweed (5, 41) spreads by lateral growth of underground parts or by seed. The roots[1] may penetrate the soil to depths of 6 m or more. The main roots are long whitish cords of variable diameter with many lateral branches. Shoot buds arising on laterals develop rhizomes that grow to the surface and establish new crowns. The ability to produce underground buds and store food reserves in its roots are the primary reasons that this plant is difficult to eliminate.

Early methods of controlling this weed included: repeated cutting of above ground growth, pasturing with hogs or sheep, salting, and smothering techniques with tar paper, manure or straw (15, 18, 46).

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[1]The roots of field bindweed consist of primary root stalks, secondary roots, lateral roots and underground stems. The term root will be used throughout this discussion in reference to all parts unless specific parts are specified.

These methods have since been replaced by methods more practical for field use.

Intensive cultivation has long been recognized as a method of controlling field bindweed. Several authors (36, 50, 52) have reported that repeated tillage at 12-day intervals after field bindweed emergence was as effective in root reserve depletion as more frequent intervals. These authors also showed that cultivation deeper than 10 to 12.5 cm did not decrease the time necessary for field bindweed elimination enough to justify the added expense of the deeper tillage. Numerous authors (7, 8, 35, 50, 52) have found that the use of repeated cultivation generally requires from 2 to 3 years for elimination of established field bindweed stands.

Competitive crops have been tested for controlling field bindweed. Alfalfa (Medicago sativa L.), sorghum (Sorghum vulgare), and sudangrass (Sorghum vulgare sudanense) were much more effective if established after one year of intensive fallow (5, 15, 18). However, results were variable and established field bindweed stands were seldom eliminated. Phillips (35) reported that one year of intensive cultivation followed by three years of winter wheat (Triticum aestivum L.) with intensive tillage between harvest and reseeding were effective in eradicating field bindweed.

Chemical control of field bindweed was initiated with the discovery of sodium chlorate. This led to many other non-selective chemicals such as: borate compounds, urea herbicides, benzoic acids, and picloram (6, 27, 35, 50). These treatments are effective for controlling field bindweed but are expensive and limited to small acreages. Also, these treatments often leave the soil unproductive for several years.

The effectiveness of (2,4-dichlorophenoxy)-acetic acid (2,4-D) on broadleaf weeds prompted many researchers to examine its potential for controlling field bindweed. Phillips (35) and Wiese and Rea (53, 54) found that 2,4-D used alone was effective as a field bindweed growth retardant, but it was not effective in eliminating this weed even with repeated applications. The use of 2,4-D as a supplemental treatment in cropping and cultivation systems reduced field bindweed stands in studies conducted by Phillips (35) and Derscheid, Stritzke, and Wright (19). Derscheid et al. reported that field bindweed stands could be reduced 90% or more in a 3-year period of continuous wheat by applying 2,4-D in the spring when the field bindweed and wheat were actively growing and then applying 2,4-D or intensively cultivating between harvest and reseeding of the wheat.

A new approach to controlling field bindweed is being evaluated and is the subject of this thesis. Recent research (3, 26, 33) has found that field bindweed is effectively controlled by a uniform layer of trifluralin 4 to 6 inches beneath the soil surface. Field bindweed growth is contained beneath the layer. This method appears promising for eradication of field bindweed if the roots are physiologically weakened or food reserves depleted enough that eradication can be obtained prior to dissipation of the trifluralin layer.

Some characteristics of trifluralin persistence in soil have been determined. Incorporation of trifluralin into the soil increases its persistence by decreasing photodegradation (55) and volatility losses (10, 43). Greater soil persistence of trifluralin with increased incorporation depth was demonstrated by several researchers (10, 32, 43). Messersmith, Burnside, and Lavy (31) reported inverse relationships of trifluralin soil persistence with both temperature and water content of the soil. Bardsley, Savage, and Childers (9) found more retention of active trifluralin in soils of higher organic matter, indicating greater retention of the vapor phase of this herbicide. Anderson, Richards, and Whitworth (2) found trifluralin very resistant to leaching in soil columns. Arnold (3) reported approximately 25 percent of the original trifluralin remained in the soil 15 months after applying the trifluralin layer at a 10 cm soil depth.

Trifluralin inhibits root growth on numerous plant species (13, 21, 25). These researchers generally found radial enlargement of the primary roots near the meristematic tip and decreased formation of secondary roots. Talbert (49) reported that trifluralin's inhibition of soybean (Glycine max (L.) Merr.) root growth was caused by blocking mitosis in the prophase stage. Bayer et al. (13) and Lignowski and Scott (29) agreed with Talbert on trifluralin's disruption of mitotic cycle but did not find specific stages of blocking of mitosis. However, Lignowski indicated possible blocking of metaphase along with inhibition of normal spindle apparatus formation.

Knake, Appleby, and Furtick (25) reported localized application of trifluralin to the green foxtail (Setaria viridis) root resulted in essentially no injury to the shoot but localized application to the shoot caused severe inhibition of shoot growth. Swann and Behrens (48) supported this result with foxtail and proso millet (Panicum miliaceum L.). These results indicate little or no translocation of trifluralin from the root to the shoot of these plants. Strang and Rogers (47) found ^{14}C-trifluralin was absorbed onto the external root surface of cotton (Gossypium hirustem L.) and soybeans with increased absorption and deeper penetration in areas where disease or mechanical damage had broken the epidermal layer.

The molecular fate of trifluralin in plants is not well understood. Golab et al. (22) and Probst et al. (37) reported approximately 90% of ^{14}C-trifluralin absorbed into carrot roots was unaltered trifluralin molecules. However, Biswas and Hamilton (14) found extensive degradation of trifluralin in peanuts and sweet potatoes.

Field bindweed root reserve energy must be depleted prior to dissipation of the trifluralin layer for effective elimination of this weed. Since the literature indicates trifluralin does not translocate readily, a herbicide that is easily translocated through field bindweed roots might give better elimination of this weed if mixed with trifluralin. Dicamba is translocated rapidly in broadleaf plants; therefore, it was selected as a desirable complimentary herbicide.

Several authors (17, 23, 28, 30) have reported rapid absorption by roots and translocation of dicamba throughout numerous plant species. Also, many researchers (16, 23, 30, 38, 40) have reported rapid absorption by leaves and translocation to other parts of the plant in several different species. These results indicate that dicamba may be absorbed by either the roots or leaves of plants and readily translocated in both the apoplastic and symplastic plant systems.

MATERIALS AND METHODS

Experiments were initiated near Winner and Presho, S.D., to evaluate the control of field bindweed with subsurface layered treatments of trifluralin, dicamba, and combinations of these herbicides. The effect of subsurface treatments on the reserves of field bindweed roots were analyzed in an experiment near Redfield, S.D. A laboratory study was conducted to trace the movement of these herbicides in the roots of field bindweed.

The experimental areas at Winner and Presho were fallowed during the summer and planted to winter wheat in the fall. Experiments were conducted near Beresford and Redfield, S.D., to determine the phytotoxicity of these herbicide treatments to corn.

The Effect of Subsurface Herbicide Layers on Field Bindweed

Field Bindweed Control

Factorial experiments in a randomized complete block design were used to evaluate field bindweed control. Factors used were trifluralin at 0.00, 1.12, 2.24, and 3.36 kg/ha and dicamba at 0.00, 0.56, and 1.12 kg/ha. Each level of one factor was combined with each level of the other factor.

Herbicides were applied 20 cm beneath the soil surface in a uniform horizontal layer. Subsurface layering was done with a 1.83 m noble blade equipped with eleven 8001 Tee Jet nozzles beneath the blade. The nozzles delivered 309 L/ha spray solution at 2.8 kg/cm^2 with a ground speed of 4.8 km/hr. The effective spray swath under the blade was 1.68 m. Photographs of the subsurface herbicide layering implement are presented in Figure 1. A preemergence treatment of 2-Chloro-N-isopropylacetanilide (propachlor) plus 2-(4-chloro-6-ethylamino-S-triazin-2-ylamino)-2-methylpropionitrile (cyanazine) at (3.36 + 1.68 kg/ha) was applied over the experiments for annual weed control.

Five replications of the basic experiment were used at Winner. Each experimental unit was 6.7 m by 6.7 m. Replications were oriented perpendicular to a sloping hillside. The experimental area had a silty clay loam texture and a pH of 8.0. The percent organic matter was 2.4 in replications one and two, 2.0 in replications three and four, and 1.6 in replication five near the hilltop.

Field bindweed was known to have been present in the experimental area for a minimum of five years. Sorghum was grown on the experimental area the year prior to this experiment and cultivation was the only method used to control field bindweed. The experiment was tilled once with an offset tandem disk two weeks prior to the June 8 layering of the herbicides. Field bindweed regrowth ranged from having just emerged to having a 25 cm vine at the time of herbicide layering.

Field bindweed stand counts were taken in four 0.84 m^2 evenly spaced locations along the diagonal of each experimental unit. Stand counts were taken on June 28, July 19, August 23, and October 27. The experiment was disked with an offset tandem disk early in August.

Six replications of the basic experiment were used at Presho. Individual plot size was 3.7 m by 10.7 m. The soil was of a silty clay texture, with 2.2% organic matter and a 7.9 pH. Field bindweed was known to have been established in the experimental area for a minimum of twenty years. Sorghum had been grown on the area the year prior to

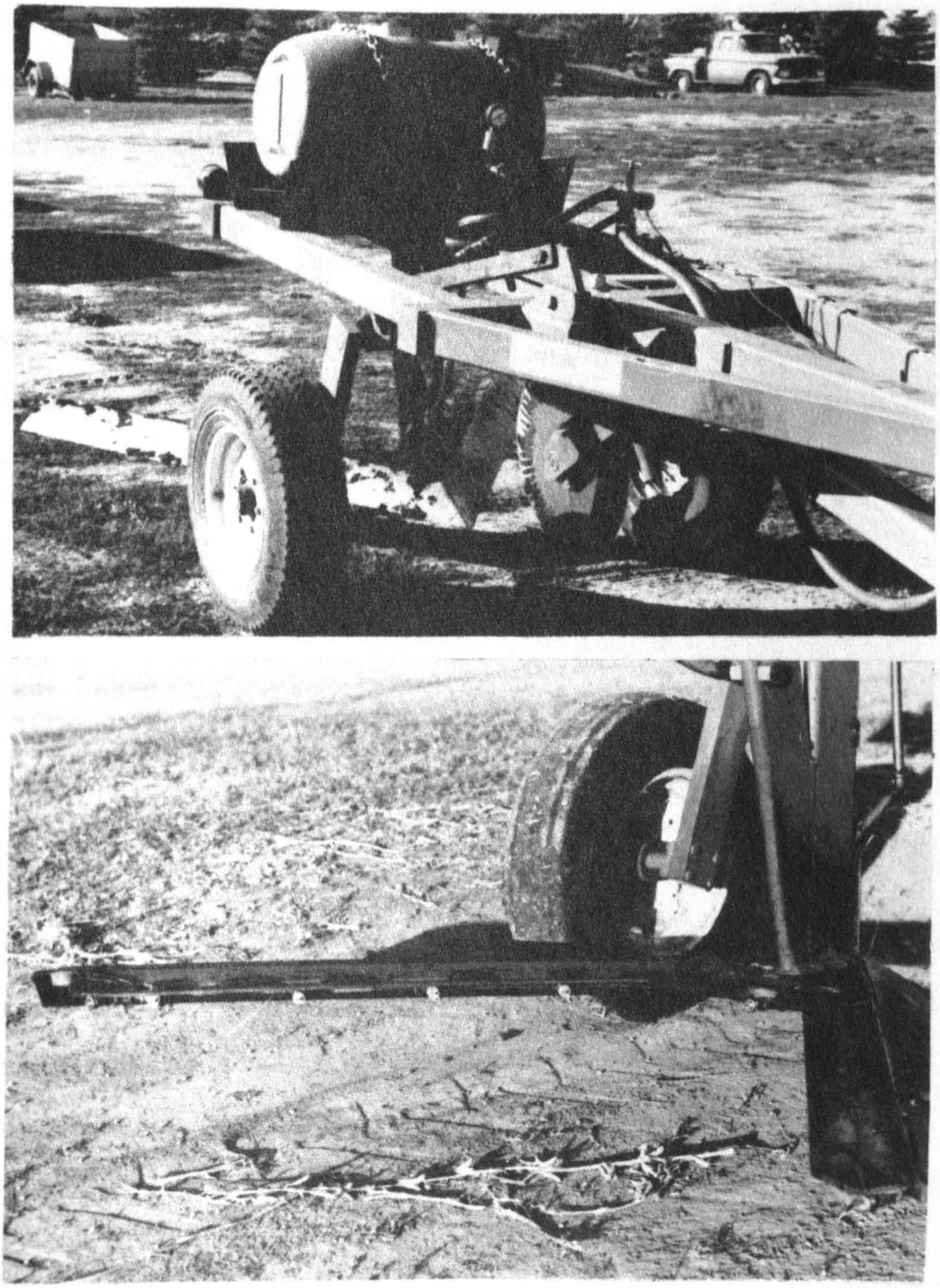

Figure 1. The implement used for subsurface layering of herbicides. (upper) General view (lower) Boom and nozzle system under the blade.

the experiment. Cultivation and 2,4-D amine were used to control field bindweed in the sorghum.

The experiment was tilled once with a oneway disk one day prior to subsurface layering of herbicides on June 13. Field bindweed plants ranged from 15 to 35 cm in length at the time of tillage.

Field bindweed stand counts were taken from four 0.84 m^2 areas in each experimental unit as previously described. These counts were made June 29, July 19, and August 23 with counts being made over the same areas on each succeeding counting date.

Analysis of Carbohydrate Reserves in Field Bindweed Roots

An experiment was conducted to determine the effectiveness of subsurface herbicide layers to deplete carbohydrates in field bindweed roots. Soil in the experimental area was of a silty loam texture with 3.0% organic matter and a 7.8 pH.

The 30 m by 43 m experimental area was divided into five 6 m by 43 m plots. The five treatments included were: control, mechanical fallow, trifluralin 2.24 kg/ha, dicamba 1.12 kg/ha, and trifluralin plus dicamba (2.24 + 1.12 kg/ha). The control and mechanical fallow treatments were bladed with the subsurface layering implement on June 6, 1973. Herbicide treatments were layered beneath the soil surface also on June 6. The subsurface layering implement used in this study was different from that used at Winner and Presho. Three 76 cm sweeps were equipped with one 15002 Tee Jet nozzle mounted under the center of each sweep and one 730039 Tee Jet nozzle mounted under each wing. The unit layered 281 L/ha of spray solution 18 cm beneath the soil surface when operated at 4.3 km/hr and 2.8 kg/cm^2. A preemergence treatment of 2-chloro-2', 6'-diethyl-n-(methoxymethyl)-acetanide (Alachlor) plus 2-chloro-4-ethylamino-6-isopropylamino-S-triazine (atrazine) at (2.24 + 1.12 kg/ha) was applied for annual weed control.

The experiment had been moldboard plowed May 3 and tandem disked May 23. The fallow plot was then tandem disked on June 26, July 17, August 10, and September 6.

Field bindweed growth was subsampled 10, 13, and 19 m from one end of the plots and near the center of the 6 m dimension on September 22. Wet and dry weights of field bindweed growth above the soil surface were determined from a 60 cm by 60 cm area at each subsample location. Field bindweed roots were excavated from a depth of 60 cm directly beneath the foliage sampling locations.

The field bindweed roots were washed in cold water to remove soil particles and wet weights were recorded. These roots were placed in an oven at 100 C for one hour to stop carbohydrate metabolism. The roots were then transferred to an oven at 70 C and left until dry. The roots were ground through a 1 mm screen and analyzed for their total non-structural carbohydrate content. Reducing sugars, sucrose, and starch contents were determined. The methods of Raguse and Smith (39) and Smith (44) were used for carbohydrate analysis with the only modification being in the first extraction where 80% (v/v) ethanol at room temperature was used to remove the sucrose and reducing sugars.

Visual inspection of the field bindweed in this experiment indicated the presence of a heavy, uniform infestation. Therefore, statistical analyses were performed by using within treatment (subsample) error to test the significance of treatment effects.

Absorption and Translocation of Herbicides in Field Bindweed Roots

Field bindweed seeds were germinated by a method described by Andersen (1). Three days after germination, the seeds were transferred to cylindrical columns. The columns had a 10 cm removable segment on top of a 61 cm segment to allow application of herbicides beneath the soil surface. The columns had an inside diameter of 10 cm. The soil in the columns was a greenhouse mix of a silty clay loam soil with 4.1% organic matter and 7.0 pH, sand, and ground peat in a ratio of 7:3:1 (v/v). Screens were attached over the base of the columns to retain the soil and to allow drainage. The field bindweed plants were grown in the soil columns outdoors for five months. The field bindweed roots had grown through the soil in the column and had penetrated through the screen at the base. Four weeks before treatment, these plants were transferred to the greenhouse and their foliage was cut back to the soil surface. No artificial lighting was used in the greenhouse.

Radioactive and technical grade forms of trifluralin and dicamba were used to study absorption and translocation of these herbicides in field bindweed roots. Trifluralin, with a specific activity of 10 μc/mg and a radiochemical purity greater than 98%, was labeled with a carbon-15 radioisotope in the trifluoromethyl group. Technical grade trifluralin was 95% pure. A carbon-14, carboxyl labeled form of dicamba was used in this study. The specific activity of this compound was 22.7 μc/mg and its radiochemical purity was 99%. Technical grade dicamba was 89% pure.

These herbicides were combined with a 70 gm soil mixture. The soil mixture was soil of a silty clay loam texture, 4.1% organic matter and 7.0 pH mixed with sand in a ratio of 1:1 (w/w). Trifluralin and dicamba were dissolved in acetone and ethanol. The herbicide treatments combined with soil, followed in parenthesis by the amount and concentration of solutions used in their preparation are:

1. ^{14}C-trifluralin (0.7 ml of 0.0030 M ^{14}C-trifluralin plus 1.0 ml of 0.0040 M trifluralin)
2. ^{14}C-trifluralin plus dicamba [same as (1) plus 1.0 ml of 0.0046 M dicamba]
3. ^{14}C-dicamba (0.7 ml of 0.0020 M ^{14}C-dicamba plus 1.0 ml of 0.0032 M dicamba)
4. ^{14}C-dicamba plus trifluralin [same as (3) plus 1.0 ml of 0.0061 M trifluralin]
5. Control (1.7 ml of acetone plus 1.7 ml of ethanol)

Radioactivity was 7 μc per soil treatment for both ^{14}C-trifluralin and ^{14}C-dicamba. Acetone and/or ethanol were added to bring the total amounts of each solvent to 1.7 ml in each soil treatment.

For treatment, field bindweed plants were cut back to the soil surface again, the top 10 cm section of the column was removed, and approximately 2 cm of soil was removed from the top of the 61 cm column segment. Molten paraffin was used to seal the column so that the primary field bindweed root was penetrating through the paraffin layer. The primary root was cut off 3 mm above the paraffin layer. Photographs of the experimental procedures are presented in Figure 2. Each herbicide treatment was mixed thoroughly with soil which was then added above the paraffin layer. This soil formed a 5 mm zone above the paraffin layer. The soil treatments were mixed for a 2.24 kg/ha rate of trifluralin and/or a 1.12 kg/ha rate of dicamba based on the cross-sectional

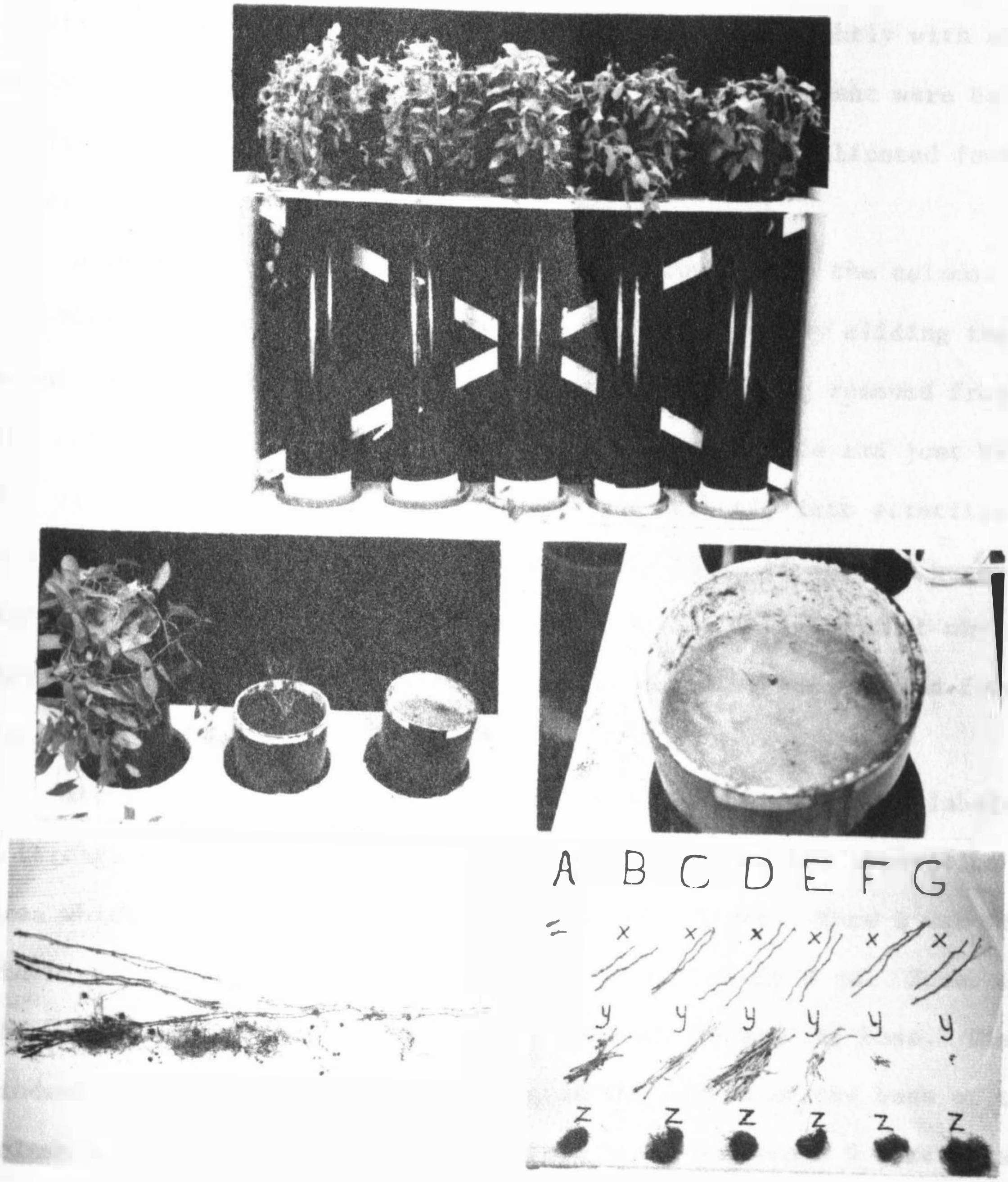

Figure 2. The procedures used in the herbicide translocation study. (upper) Field bindweed growth in columns. (left center) Field bindweed trimmed and molten paraffin applied. (right center) Primary root of field bindweed penetrating through the paraffin layer prior to application of treated soil. (lower left) Field bindweed roots removed from the column. (lower right) Field bindweed roots classified by zones from the top to the bottom (A through G) of the column and by tissue; x-primary root, y-new shoots and z-secondary roots.

area of the column. Fifteen milliliters of distilled water were added to the treated soil and then the column was covered tightly with aluminimum foil. The five treatments in the basic experiment were each applied by these methods. The basic experiment was replicated four times in a randomized complete block design.

After 48 hours, the treated soil was removed from the column. The field bindweed plant was removed from the column by sliding the plant and soil out the bottom. As the plant was being removed from the column, soil samples were taken at the base, middle and just below the paraffin layer. These samples were put directly into scintillation vials and 5 ml of methanol and approximately 15 ml of aquasol were added. These samples were analyzed for possible activity that may have leached through the paraffin layer or may have been exuded from field bindweed roots.

The field bindweed roots were sectioned into seven zones labeled A through G from top to bottom. Zone A consisted of the absorption area which extended to just below the paraffin layer. Zone B was from the base of the paraffin layer downward approximately 8 cm. Zones C through G were 10 cm each progressing downward toward the base. Field bindweed root growth that had penetrated the screen at the base of the column was disposed. Plant tissues from Zones B through G were separated and classified as either primary roots, new shoots (including buds breaking dormancy), or secondary roots. Photographs of field bindweed roots are presented in Figure 2.

Each individual sample was washed with cold tap water, blotted dry, and then lyophilized with condenser temperature of -54 C for

20 hours. Dried plant tissues were ground with mortar and pestle; dry weights were recorded; and 25 mg were taken from each sample for radioactivity analysis. The 25 mg samples were placed directly into scintillation vials; 0.5 ml distilled water was added; vials were sealed; and 60 C heat was applied for 12 hours. One milliliter of Soluene 350 was then added to each vial. These vials were sealed and placed in 60 C environment for 24 hours to solubilize the plant tissues. Glacial acetic acid (0.25 ml/vial) was added to minimize possible artifactual counts from chemiluminescence. Aquasol containing 40 gm/L of Cabo-o-sil suspending medium was used as the scintillator fluid. Radioactivity was determined with a Packard model 3375 Tri-Carb Liquid Scintillation Spectrometer. Counting efficiencies were determined by the channels ratio method.

The Phytotoxicity of Subsurface Herbicide Layers to Crops

Phytotoxicity to Winter Wheat

The field bindweed control experiments at Winner and Presho were seeded to winter wheat in September, 1973. Measurements of the effect of subsurface herbicide treatments on the winter wheat were made on October 27, 1973.

Scout 66 winter wheat was seeded at 78 kg/ha in 17.8 cm drill-row widths on September 5 at Winner. The experiment was offset tandem disked prior to the seeding of winter wheat. A systemic insecticide, O,O-Diethyl S-(ethylthio)-methyl phosphorodithioate (phorate) at 1.1 kg/ha formulated in 15% granules, was applied with a grass seeding attachment on the grain drill for green bug (*Schizaphis graminum*) control. Stand counts of winter wheat were taken from 0.91 m in one drill row in each field bindweed counting area. Winter wheat forage samples were taken from 0.91 m in two drill rows in each experimental unit. These forage samples were oven dried and their dry weights were recorded.

Scout 66 winter wheat was seeded at 78 kg/ha in 25.4 cm drill-row widths on September 6 at Presho. The experiment was tilled with a oneway prior to seeding; this was the first tillage since the treatments were applied on June 13. A poor stand of winter wheat emerged and another tillage was necessary to destroy the winter wheat that had emerged. Reseeding was done on September 29. Phorate at 1.0 kg/ha formulated in 15% granules was applied with a grass seeding attachment on the drill to control green bug.

Stand counts and forage harvest of winter wheat were taken from five and two replications, respectively. The methods of collecting these data were the same as those used at Winner.

Phytotoxicity to Corn

The experimental design and factors used in the experiments near Winner and Presho were also used on the corn (Zea mays L.) experiments near Beresford and Redfield. Three and four replications of the basic experiment were used at Redfield and Beresford, respectively. Subsurface herbicide layers were applied by the same implement and the same methods that were described earlier in the analysis of carbohydrate reserves in field bindweed roots.

Basic experimental units were 3.8 m by 7.3 m. Corn was planted in 76 cm row spacings allowing five rows per plot. The second and fourth rows were used for evaluation purposes to avoid data from rows planted directly over the outside margins of the blade where either a doubled rate or no herbicide may have been applied. Alachlor plus atrazine at (2.24 + 1.12 kg/ha) was applied immediately after corn planting for annual weed control.

Soybeans had been grown the previous year on the experimental area near Beresford. After soybean harvest, the area was fall plowed. The soil was of silty loam texture with 3.0% organic matter and a 6.6 pH. Herbicide treatments were applied on June 1. The seedbed was prepared by tandem disking and dragging, and 45,700 seeds/ha of Pioneer 3579 hybrid seed corn were planted on June 1.

Data measurements included corn stand counts from 12.2 m lengths of row on June 14 and again over the same area on October 6. Extended leaf height measurements were made June 27 and July 16 with tassel heights measured October 6. Heights of four plants were recorded in each experimental unit. Corn grain and forage harvest samples from 12.2 m lengths of row and root extraction pressures of four plants were taken from each plot on October 6. Grain and forage moisture samples were used to determine grain yields at 15.5% moisture and forage yields in kilograms dry matter per hectare.

A similar experiment was conducted near Redfield on a silty clay loam soil with 2.8% organic matter and a 7.6 pH. Three replications of the basic experiment were used. Herbicide layering, seedbed preparation, and planting of Jacques 952 hybrid seed corn were done on June 6. Data were taken at Redfield by the same methods that have been described for Beresford. Stand counts were made June 19 and October 8. Extended leaf height and tassel height measurements were made July 17 and August 23, respectively. Corn grain yields, forage yields, and root extraction pressures were measured October 8.

RESULTS AND DISCUSSION

The Effect of Subsurface Herbicide Layers on Field Bindweed

Field Bindweed Control

Field bindweed stand counts at Winner and Presho are shown in Tables 1 and 2. Field bindweed shoots from root segments above the subsurface herbicide layer[2] were weak and did not survive. However, these plants caused variability in the June stand counts. Rainfall from the time of subsurface application through August was 20.2 cm at Winner and 9.7 cm at Presho. The increased rainfall at Winner may have reduced the control of field bindweed.

At Winner, field bindweed control from dicamba decreased in July and no control was evident in August. Field bindweed control with trifluralin plus dicamba (1.12 + 0.56 kg/ha) was not significantly different from field bindweed control with trifluralin at 3.36 kg/ha. The combination treatment of 2.24 + 1.12 kg/ha tended to be the most effective treatment. Photographs of field bindweed control at Winner are shown in Figure 3.

Lower rates of herbicides were required to obtain effective control of field bindweed at Presho than were required at Winner. Dicamba at 0.56 kg/ha controlled field bindweed effectively in July, but gave less control in August. Control in August with the combination of trifluralin plus dicamba (1.12 + 0.56 kg/ha) was better than

[2]All herbicide treatments in field experiments were applied in a subsurface layer. Therefore, the application method will not be included when reference is made to specific treatments.

Table 1. Field bindweed stand counts from the Winner location. Subsurface layered trifluralin and/or dicamba treatments were applied June 8.

Treatment Trifluralin + Dicamba kg/ha	Field Bindweed Stand Counts Plants/0.84 m^2*			
	June 28	July 19	Aug. 23	Oct. 27
0.00 + 0.00	9.4 a	18.4 a	11.2 ab	5.8 b
0.00 + 0.56	3.3 b	8.0 b	12.4 a	10.4 a
0.00 + 1.12	2.7 b	4.7 bc	13.0 a	10.3 a
1.12 + 0.00	5.1 b	5.6 bc	10.4 ab	3.8 bc
1.12 + 0.56	2.5 b	2.6 c	2.5 c	2.6 bc
1.12 + 1.12	4.6 b	2.4 c	2.3 c	3.2 bc
2.24 + 0.00	6.3 ab	6.4 bc	6.2 bc	2.3 bc
2.24 + 0.56	4.6 b	2.5 c	2.9 c	1.2 c
2.24 + 1.12	3.9 b	1.5 c	1.4 c	0.4 c
3.36 + 0.00	3.0 b	3.3 bc	4.0 c	1.1 c
3.36 + 0.56	4.0 b	2.5 c	3.0 c	0.9 c
3.36 + 1.12	4.4 b	1.2 c	1.0 c	0.7 c

*Means followed by the same letter (for within date comparisons only) do not differ significantly when compared by Duncan's Multiple Range Test at the 95% confidence level.

the control obtained with either herbicide used alone at these same rates and as effective as higher rates of either herbicide used alone. However, higher rates of the trifluralin plus dicamba combinations appeared to give additional reductions in field bindweed stands.

Field bindweed roots were excavated from the control, dicamba at 1.12 kg/ha, trifluralin at 2.24 kg/ha, and trifluralin plus dicamba combination at 2.24 + 1.12 kg/ha on August 25 at Presho. The photographs in Figure 4 show the field bindweed underground shoot development from these plots. The dicamba treatment did not appear to affect

Table 2. Field bindweed stand counts from the Presho location. Subsurface layered trifluralin and/or dicamba treatments were applied June 13.

Treatment Trifluralin + Dicamba kg/ha	Field Bindweed Stand Counts Plants/0.84 m2*		
	June 29	July 19	Aug. 23
0.00 + 0.00	2.5 ab	12.3 a	13.2 a
0.00 + 0.56	2.0 ab	1.5 c	3.6 b
0.00 + 1.12	1.6 ab	1.1 c	1.5 c
1.12 + 0.00	3.8 a	3.8 b	4.0 b
1.12 + 0.56	2.8 ab	1.6 c	1.2 c
1.12 + 1.12	2.5 ab	1.3 c	0.6 c
2.24 + 0.00	2.9 ab	2.2 bc	2.2 bc
2.24 + 0.56	2.1 ab	1.4 c	1.5 c
2.24 + 1.12	1.7 ab	1.1 c	0.4 c
3.36 + 0.00	1.2 b	0.8 c	1.2 c
3.36 + 0.56	1.3 b	0.8 c	0.5 c
3.36 + 1.12	0.9 b	0.7 c	0.2 c

*Means followed by the same letter within dates of observation do not differ significantly when compared by Duncan's Multiple Range Test at the 95% confidence level.

underground shoot development when compared to the control. The trifluralin treatment caused an initiation of new shoots at the subsurface layer, but these shoots did not penetrate the layer. The combination of trifluralin plus dicamba appeared to cause proliferation of new shoots at the subsurface treatment layer, but these shoots deteriorated at an early development stage. The effects of these subsurface herbicide layers on field bindweed roots were examined more thoroughly and are the topic of discussion in the following section of this thesis.

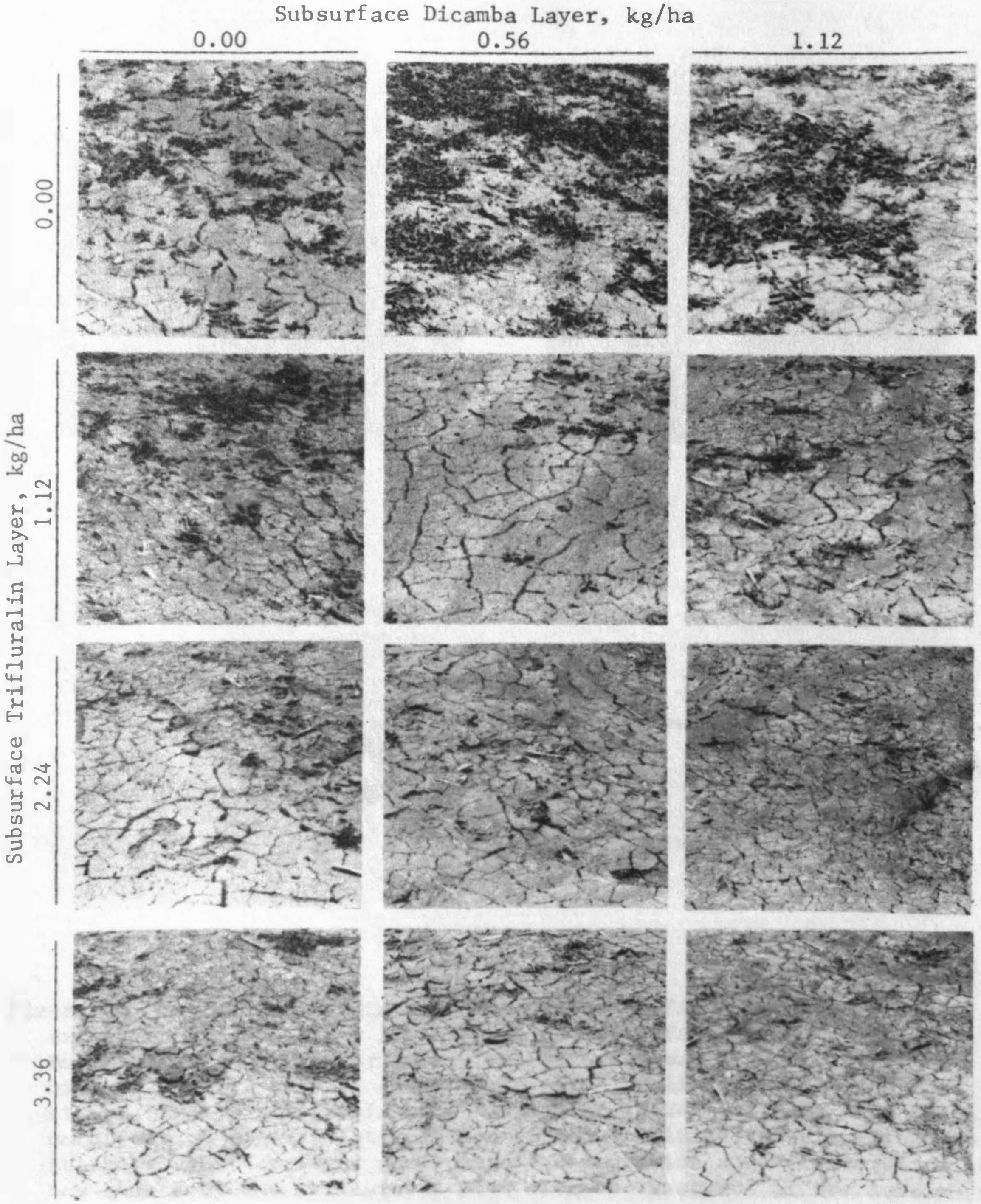

Figure 3. Field bindweed plots at Winner 82 days after herbicide applications. Herbicide rates are continuous through their respective row or column.

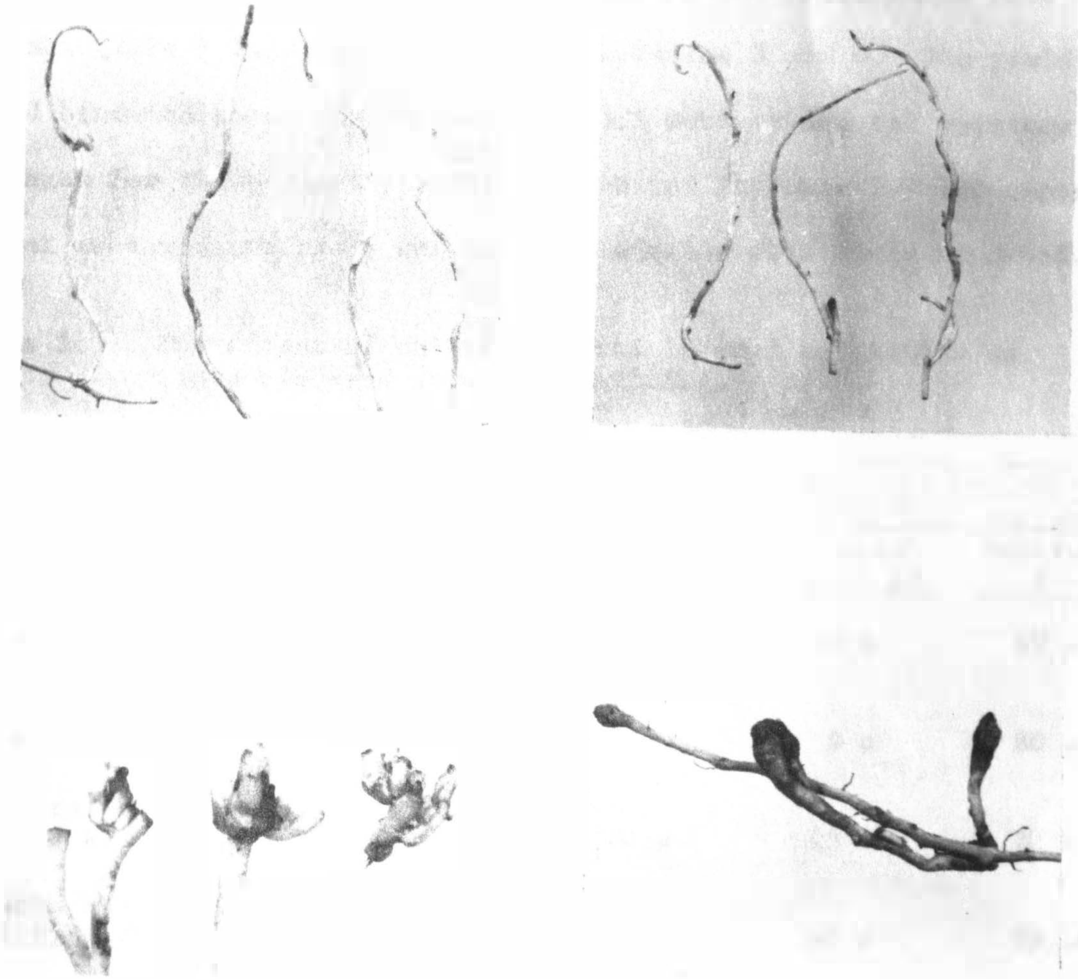

Figure 4. The underground shoot development of field bindweed plants excavated 73 days after application of subsurface herbicide treatments at Presho. (upper left) Control treatment. (upper right) Dicamba at 1.12 kg/ha. (lower left) Trifluralin at 2.24 kg/ha. (lower right) Trifluralin plus dicamba at (2.24 + 1.12 kg/ha). Note; no effect by dicamba, stimulation of shoot initiation by trifluralin at the subsurface layer and apparent stimulation and deterioration of new shoots by the trifluralin plus dicamba treatment at the subsurface layer.

Analysis of Carbohydrate Reserves in Field Bindweed Roots

Field bindweed growth as affected by mechanical fallow or by trifluralin (2.24 kg/ha), dicamba (1.12 kg/ha), and trifluralin plus dicamba (2.24 + 1.12 kg/ha) is shown in Tables 3 and 4. The yield of field bindweed above and beneath the soil surface and the moisture percentages for these plant parts are presented in Table 3. The experimental area was uniformly and heavily infested with field bindweed.

Table 3. The effect of cultivation and layered herbicides on field bindweed growth at Redfield.

	Field Bindweed Yields and Moisture Content*			
	Above Soil Surface		Beneath Soil Surface	
Treatments	Dry Yield gm/0.37 m^2	Moisture %	Dry Yield+ gm/0.23 m^3	Moisture %
No Herbicide, control	83 a	69 a	50 b	67 a
No Herbicide, mechanical fallow‡	0 b	-	9 c	80 c
Trifluralin 2.24 kg/ha	10 b	70 a	13 c	72 b
Dicamba 1.12 kg/ha	60 a	71 a	65 a	70 ab
Trifluralin + Dicamba (2.24 + 1.12 kg/ha)	0 b	-	2 d	79 c

*Within column means followed by the same letter do not differ significantly when analyzed by Duncan's Multiple Range Test at the 95% confidence level.

+Roots were removed from soil to a 60 cm depth directly below the foliage samples.

‡Mechanically fallowed plot was tilled seven times at approximate 3-week intervals from spring to harvest.

Table 4. The effect of cultivation and layered herbicides on the nonstructural carbohydrate content of underground field bindweed parts removed from the upper 60 cm soil zone.

Treatments	Carbohydrate Content, % of dry matter* — Fractions of TNC+ — Reducing Sugars	Sucrose	Starch	Total TNC
No Herbicide, control	0.7 a	5.6 a	19.7 a	26.0 a
No Herbicide, mechanical fallow‡	0.6 a	2.4 b	4.7 b	7.7 b
Trifluralin 2.24 kg/ha	0.8 a	7.1 a	23.7 a	31.6 a
Dicamba 1.12 kg/ha	0.8 a	6.9 a	20.1 a	27.8 a
Trifluralin + Dicamba (2.24 + 1.12 kg/ha)	0.5 a	3.1 b	1.7 b	5.3 b

*Within column means followed by the same letter do not differ significantly when analyzed by Duncan's Multiple Range Test at the 95% confidence level.

+TNC - refers to the total non-structural carbohydrates.

‡Mechanically fallowed plot was tilled seven times at approximate 3-week intervals from spring to harvest.

The mechanically fallowed treatment was cultivated seven times during the season. Field bindweed shoots had not emerged from this treatment that had last been cultivated 16 days prior to the September 22 harvest of field bindweed plant parts. The dicamba treatment prevented field bindweed growth for approximately one month after subsurface layering but then numerous plants emerged. The field bindweed stand appeared to be less intense than the weedy check at harvest. Only scattered field bindweed plants emerged through the trifluralin layer.

The subsurface layer of trifluralin plus dicamba prevented penetration of field bindweed shoots through the layer for the entire growing season.

Field bindweed plants in the control treatment had matured through seed production and were beginning senescence at the time of harvest. Field bindweed plants remaining in the trifluralin and dicamba treatments were more vigorous and had not matured as much as plants in the control treatment; however, some seed pods had developed in both of these treatments. The increased vigor of plants in the trifluralin and dicamba treatments was attributed to delayed emergence and less intense stands of field bindweed.

Dry matter yield of field bindweed roots in the upper 60 cm of soil was reduced by the mechanically fallowed, trifluralin, and trifluralin plus dicamba treatments. Trifluralin plus dicamba gave nearly complete elimination of field bindweed roots in the upper 60 cm of soil. The moisture percentage of field bindweed roots was increased in the mechanically fallowed and those herbicide treatments which reduced root yields. This increased moisture appears attributable to the more active metabolism of the less mature, treated plants. The highly succulent roots of the mechanically fallowed and the trifluralin plus dicamba treatments are important since this would indicate continued active metabolism and thereby continued depletion of the carbohydrate reserves in these field bindweed roots.

An analysis of the carbohydrate reserves in these roots is presented in Table 4. Total non-structural carbohydrates were reduced significantly by the mechanically fallowed and the trifluralin plus dicamba (2.24 + 1.12 kg/ha) treatments. The starch fraction accounted for most of the reduction in carbohydrates. Starch is the primary form for carbohydrate storage in field bindweed (7, 8, 11).

The mechanical fallow and the herbicide combination treatments also decreased the sucrose content and appeared to decrease the reducing sugars content in field bindweed roots. Sucrose is believed to be the most mobile form of carbohydrate in higher plants. Reducing sugars are the form of reserve energy most readily available for energy release by oxidation in plant respiration. Both sucrose and reducing sugars may be present as a product of photosynthesis or as a product of starch decomposition (42).

The field bindweed roots of the mechanically fallowed and the herbicide combination treatments were not building carbohydrates by photosynthesis. Therefore, the sugar content, although reduced, would indicate a continuing respiration of the plant and depletion of the remaining starch. The total non-structural carbohydrate content of the subsurface layer of trifluralin plus dicamba was 5.3 percent of the dry matter weight of field bindweed roots. Bakke et al. (8) reported that field bindweed was eradicated in three experiments when total available carbohydrate contents were reduced to 3, 4, and 7% of dry weight, respectively.

The dicamba and trifluralin treatments did not reduce the total non-structural carbohydrate contents. The dicamba treatment had abundant above ground foliage to produce energy reserves by photosynthesis. Trifluralin allowed very little plant growth above the soil surface, but these roots appeared to have a higher carbohydrate content than the roots in the control treatment. A possible explanation is that trifluralin allowed very little growth above its subsurface layer. Therefore, a greater proportion of the root weight would be from a lower soil horizon. This explanation is supported by the work of Bakke et al. (8) who found higher percentages of available carbohydrates in lower soil horizons. Also, the reduced amount of roots in the trifluralin treatment may require less photosynthesizing material above the soil surface to maintain a high level of carbohydrate reserves. Another explanation would be that field bindweed reaches its highest carbohydrate content near the time of seed production and gradually decreases through the remainder of the season (4, 7, 12). The delayed maturity of trifluralin and dicamba treated field bindweed could then result in higher carbohydrate contents in the September harvested roots.

Trifluralin plus dicamba (2.24 + 1.12 kg/ha) was very effective in reducing the total non-structural carbohydrate content of field bindweed roots. Kennedy and Crafts (24) found that living parenchyma cells of the cortex and secondary phloem are the primary energy storing cells in field bindweed roots. Pate et al. (34) reported destruction of cortical parenchyma and phloem tissues of alligatorweed (Alternanthera philoxeroides (Mart.) Griseb.) treated with dicamba. Therefore, the effectiveness of the combination of trifluralin plus dicamba may be explained by dicamba translocating in the field bindweed roots to depths beneath the herbicide layer and destroying the carbohydrate containing cells. Shoots initiated from far below would have to utilize tremendous carbohydrate reserves to grow up to the subsurface layer of trifluralin. These shoots may be weakened in carbohydrate strength and could be contained more effectively beneath the trifluralin layer. This hypothesis was explored in an experiment conducted to determine the movement of trifluralin and dicamba in the roots of field bindweed.

Absorption and Translocation of Herbicides in Field Bindweed Roots

No radioactivity was found in the soil samples collected from below the paraffin layer. Therefore, it was assumed that no radioactivity had leached through the layer or had been exuded from the field bindweed roots. The medium of herbicide transport was then considered to be the field bindweed root system.

The efficiency of the extraction of the radioisotopes from the plant tissue was not determined. High efficiency of extraction would be expected because of the effectiveness of Soluene 350 for solubilizing this tissue and the high solubility of trifluralin and dicamba in the solvents used in the scintillation vials. However, the extraction efficiencies for ^{14}C-trifluralin and ^{14}C-dicamba may be different. Therefore, radioactivity from these herbicides was analyzed separately to compare absorption but percentages or ratios of activities were used to compare translocation.

The total absorption and the distribution of these herbicides in field bindweed roots are presented in Table 5. The proportion of ^{14}C-dicamba translocation out of the absorption zone was far greater than ^{14}C-trifluralin. Dicamba did not significantly influence the

Table 5. The absorption and translocation of trifluralin and/or dicamba in field bindweed roots.

Treatment	Total Activity* dpm/plant	Distribution of Radioactivity in Field Bindweed Roots, %+ Distance of Recovery Zone From Treated Soil, cm						
		0	0-8	8-18	18-28	28-38	38-48	48-58
^{14}C-trifluralin	3,400 a	93.2 a	6.0 a	0.8 a	0.0 a	0.0 a	0.0 a	0.0 a
^{14}C-trifluralin + dicamba	3,000 a	87.9 a	7.0 a	1.6 a	0.5 a	2.5 ab	0.0 a	0.0 a
^{14}C-dicamba	2,042,900 b	20.3 b	50.9 b	15.1 b	7.3 b	4.0 b	1.8 b	0.4 a
^{14}C-dicamba + trifluralin	646,600 a	31.3 b	59.7 b	4.9 a	3.8 ab	0.1 a	0.1 a	0.0 a

*Comparison of treatments having the same labeled herbicide do not differ significantly, if followed by the same letter, when analyzed by Duncan's Multiple Range Test at the 95% confidence level.

+Comparisons within columns followed by the same letter do not differ significantly when analyzed by Duncan's Multiple Range Test at the 95% confidence level.

absorption of ^{14}C-trifluralin by field bindweed roots. However, dicamba appeared to increase the translocation of ^{14}C-trifluralin in these roots. Trifluralin significantly reduced the absorption of ^{14}C-dicamba. Also, trifluralin reduced the mobility of ^{14}C-dicamba in the field bindweed roots.

The lateral movement of herbicides in field bindweed roots was determined by ratios of the specific activity (dpm/mg) of new shoots and secondary roots to the specific activity of the primary roots. These ratios are presented in Table 6. No lateral movement of ^{14}C-trifluralin alone or in combination with dicamba was found.

Table 6. The translocation of trifluralin and/or dicamba from the primary field bindweed root to new shoots and secondary roots.

	Ratios of Specific Activity (dpm/mg) of Root Tissues*	
Treatment	Ratio: New Shoots to Primary Roots	Ratio: Secondary Roots to Primary Roots
^{14}C-trifluralin	0.00 a	0.00 a
^{14}C-trifluralin + dicamba	0.00 a	0.00 a
^{14}C-dicamba	0.45 b	0.18 b
^{14}C-dicamba + trifluralin	0.08 a	0.18 b

*Comparisons within columns followed by the same letter do not differ significantly when analyzed by Duncan's Multiple Range Test at the 95% confidence level.

^{14}C-dicamba was readily translocated into new shoots but this translocation was reduced when this compound was used in combination with trifluralin. However, trifluralin did not influence the movement of ^{14}C-dicamba into the secondary roots of the field bindweed plant.

These results partially explain the results obtained in the field studies. The lack of translocation by trifluralin supports the aforementioned statement that the subsurface layer only contains field bindweed root growth beneath the layer. Therefore, carbohydrate depletion in these roots would progress primarily through respiration and continued efforts of new shoots to penetrate the trifluralin layer. Dicamba was absorbed and translocated both laterally and downward when applied to simulate subsurface layering. The absorption and translocation of dicamba was reduced when applied with trifluralin, but not prohibited. Therefore, dicamba could translocate downward in field bindweed roots and destroy root tissue, resulting in more rapid depletion of the carbohydrates in these roots.

The reduced lateral movement of dicamba when applied with trifluralin may be beneficial for field bindweed control. Dicamba has auxin-like properties. Low concentrations of auxins allow activation of dormant buds. Therefore, the lower concentration of dicamba may allow buds to break dormancy. Continued accumulation of dicamba in meristematic regions of these activated buds may then result in deterioration of this tissue, as was seen in Figure 4, where the field bindweed was treated with trifluralin plus dicamba at (2.24 + 1.12 kg/ha).

The Phytotoxicity of Subsurface Layer Herbicides to Crops

Phytotoxicity to Winter Wheat

Winter wheat was seeded in the field bindweed experiments at Winner and Presho on September 5 and 29, respectively. Winter wheat stand counts and forage yield data taken prior to fall dormancy are shown in Table 7. Winter wheat growth was not affected by the dicamba factor at any levels. Therefore, observation means for each level of the trifluralin factor were determined over all rates of dicamba. Trifluralin did not affect the stand of winter wheat. However, forage yields tended to decrease as the rate of trifluralin increased and the 3.36 kg/ha rate significantly reduced the forage yield.

Table 7. Winter wheat stand counts and forage yields as affected by rates of subsurface layered trifluralin. Measurements were made at two locations on October 27.

Treatment Trifluralin kg/ha	Stand Counts plants/0.84 m^2*		Forage Yield gm dry matter/0.84 m^2*	
	Winner	Presho	Winner	Presho
0.00	37 a	73 a	16.7 a	4.0 a
1.12	37 a	68 a	14.5 ab	3.4 a
2.24	38 a	70 a	13.8 ab	3.5 a
3.36	39 a	71 a	11.0 b	3.6 a

*Within column comparisons of means followed by the same letter do not differ significantly when analyzed by Duncan's Multiple Range Test at the 95% confidence level.

Visual injury to winter wheat from trifluralin was stunting of plant growth and necrosis extending basipetally from the leaf tips. The necrosis appeared to be similar to winter wheat becoming dormant. This injury was apparent only at the Winner location. The winter wheat at Presho was planted later and had no visible injury on October 27.

Phytotoxicity to Corn

Neither visual injury nor physical measurements showed dicamba to significantly affect normal corn growth at either Redfield or Beresford. Therefore, the data observations for trifluralin are averaged over all dicamba levels to better determine the effect of trifluralin.

Corn stand counts at emergence and harvest are presented in Table 8. Trifluralin did not cause any reductions in corn stand.

Table 8. The effect of subsurface layered trifluralin rates on early and late season corn stand counts at two locations.

Treatment Trifluralin kg/ha	Corn Stand Counts, plants/9.29 m^2* Redfield June	Redfield October	Beresford June	Beresford October
0.00	37 a	40 a	31 a	37 a
1.12	36 a	38 a	32 ab	38 a
2.24	37 a	39 a	36 ab	37 a
3.36	36 a	38 a	37 b	38 a

*Within column comparisons of means followed by the same letter do not differ significantly when analyzed by Duncan's Multiple Range Test at the 95% confidence level.

Quite the contrary, a significant increase in corn plant populations at emergence was found for the 3.36 kg/ha rate at Redfield. This increase may be due to a variable stand because of dry soil conditions which delayed germination.

Corn height measurements are shown in Tables 9 and 10 for Redfield and Beresford locations, respectively. Trifluralin at 1.12 and 2.24 kg/ha tended to reduce corn heights at Redfield and 3.36 kg/ha significantly reduced heights. Corn heights were reduced at Beresford for

Table 9. Corn height measurements as influenced by subsurface layered trifluralin at the Redfield location.

Treatment Trifluralin kg/ha	Corn Heights, cm* Extended Leaf July	Tassel August
0.00	92 a	182 a
1.12	87 a	171 ab
2.24	84 ab	156 ab
3.36	79 b	152 b

*Within column comparisons of means followed by the same letter do not differ significantly when analyzed by Duncan's Multiple Range Test at the 95% confidence level.

Table 10. The effect of subsurface layered trifluralin on corn heights at the Beresford location

Treatment Trifluralin kg/ha	Corn Heights, cm*		
	Extended Leaf		Tassel
	June	July	October
0.00	35 a	128 a	238 a
1.12	33 a	120 ab	234 a
2.24	33 a	116 b	237 a
3.36	30 a	112 b	230 a

*Within column comparisons of means followed by the same letter do not differ significantly when analyzed by Duncan's Multiple Range Test at the 95% confidence level.

the July observation by the 2.24 and 3.36 kg/ha trifluralin treatments. However, height measurements at harvest showed no significant reductions. The lesser corn height suppression found at Beresford is believed to be the result of increased rainfall at that location.

Corn root extraction pressures were measured at harvest for an indication of possible inhibitions of corn root growth by the subsurface layer of trifluralin. These root extraction pressures are shown in Table 11. All rates of trifluralin reduced the pressure required to

Table 11. The effect of rates of subsurface layered trifluralin on the force (kg) required to pull corn roots from the soil. These forces were determined October 6 and 8 at Beresford and Redfield, respectively

Treatment Trifluralin kg/ha	Corn Root Extraction Pressure, kg*	
	Redfield	Beresford
0.00	61 a	98 a
1.12	45 b	81 b
2.24	43 b	66 c
3.36	48 b	70 bc

*Within column comparisons of means followed by the same letter do not differ significantly when analyzed by Duncan's Multiple Range Test at the 95% confidence level.

pull corn roots at both locations. Visual observations of extracted roots indicated limited penetration of corn roots through the trifluralin layer but increased lateral root development above the herbicide layer. Therefore, unless moisture and nutrients were limited above the herbicide layer, the corn plant could assume normal development.

Corn forage and grain yields at Redfield and Beresford are shown in Table 12. These yields are presented as dry matter but are accompanied by their respective moisture percentages at harvest. Trifluralin

Table 12. The effect of subsurface layered trifluralin on corn forage yields, grain yields, and their moisture percentages at the Redfield and Beresford experimental locations.

Treatment Trifluralin kg/ha	Corn Yields, kg dry matter/ha and Moisture, %* Forage Yield	Forage Moisture	Grain Yield	Grain Moisture
Redfield				
0.00	3070 a	74 a	4980 a	40 a
1.12	2760 ab	73 a	4340 ab	41 a
2.24	2700 ab	72 a	4340 ab	40 a
3.36	2430 b	74 a	3900 b	39 a
Beresford				
0.00	3524 a	70 a	7720 a	33 a
1.12	3386 a	70 a	7310 a	33 a
2.24	3337 a	69 a	7470 a	33 a
3.36	3431 a	68 a	7600 a	34 a

*Within locations, means within columns followed by the same letter do not differ significantly when compared by Duncan's Multiple Range Test at the 95% confidence level.

rates of 1.12 and 2.24 kg/ha tended to reduce both forage and grain yields at Redfield when compared to the control. Trifluralin at 3.36 kg/ha significantly reduced forage and grain yields. Moisture percentages were not affected. The yield reductions may be explained by the inhibitions of root growth combined with dry growing conditions. These roots would be less capable of supplying adequate moisture to the corn foliage. Trifluralin did not significantly reduce corn yields at any rate at Beresford. As previously stated, the root extraction pressures were reduced also at Beresford but this location received more rainfall than the Redfield location.

CONCLUSIONS

The experiments in this study were designed to determine the effect of subsurface layers of trifluralin and/or dicamba on field bindweed, winter wheat, and corn.

Subsurface layers of trifluralin at 1.12 kg/ha and dicamba at 0.56 kg/ha did not satisfactorily control field bindweed for one entire growing season. However, these herbicides effectively controlled field bindweed for one growing season when applied as a tank-mixed combination treatment. Higher rates of subsurface layered trifluralin, 2.24 or 3.36 kg/ha, did not improve the control that was obtained with the combination treatment. However, subsurface layered trifluralin plus dicamba at (2.24 + 1.12 kg/ha) appeared to be more effective in reducing field bindweed stands than the combination treatment at the lower rate.

The total non-structural carbohydrate content in field bindweed roots was reduced to very low levels by a subsurface layer of trifluralin plus dicamba at (2.24 + 1.12 kg/ha). This reduction in carbohydrate content was believed to be because dicamba translocated in field bindweed roots beneath the layer and destroyed root tissue. The roots then utilized more of their carbohydrate reserves growing back to the subsurface trifluralin layer and were more effectively contained by the layer. This large reduction in root reserves indicates a need for further research on this treatment to examine its potential as a means of eradicating field bindweed.

Corn and winter wheat grown over the subsurface herbicide layers indicate injury is minimal when these crops are grown over the trifluralin plus dicamba at (1.12 + 0.56 kg/ha). Injury to corn appeared to be inhibition of corn root development at the subsurface trifluralin layer. As long as moisture and nutrients are present in large enough quantities that the limited root growth can supply the plant, injury to corn is negligible.

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